Ex Vivo Renal Artery Reconstruction

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Ex vivo renal artery reconstruction and autotransplantation is a relatively recent addition to the surgical armamentarium for renal vascular hypertension. Ten consecutive patients were considered for this surgical therapy and form the basis of this communication. The patients were treated by a combination of methods including bilateral *ex vivo* reconstruction, unilateral *in situ* and contralateral *ex vivo* reconstruction, and unilateral *ex vivo* reconstruction and contralateral nephrectomy. Replacement of the diseased segment of the renal artery in all *ex vivo* reconstruction consisted of arterial autografts including hypogastric artery, splenic artery, common iliac, and external iliac artery. In the *ex vivo* reconstruction, the ureter was either left intact or was transected and reconstructed by standard ureterovesicle implantation. After surgery all patients became normotensive without antihypertensive medication. Although this is a relatively small series, the uniform good results in these patients with extensive disease suggest that *ex vivo* renal artery reconstruction is a safe and effective method of treatment. Thus, it should be more widely applicable, especially in those patients with renal vascular disease who were previously thought to be inoperable or eligible for nephrectomy only.

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FIBROMUSCULAR DYSPLASIA of the renal arteries is usually confined to the main renal artery and is repaired by *in situ* vascular reconstructive techniques. However, when fibromuscular dysplasia extends into the branches of the renal artery, *in situ* reconstruction may be difficult, hazardous, or impossible. In these instances, temporary nephrectomy and *ex vivo* repair with microvascular techniques followed by autotransplantation allows the precise repair of such lesions.[2]

Ten consecutive patients with renovascular branch lesions underwent microvascular arterial reconstruction using *ex vivo* techniques between 1972 and 1975. Indications for surgery were uncontrollable hypertension on a maximal medical regimen in all but one patient who had a symptomatic aneurysm in a solitary kidney. All were evaluated by the vascular service at the University of California, San Francisco. They are summarized in Table 1 and were considered inoperable by *in situ* methods. Five cases are described below in detail to emphasize variations in pathology and surgical approach.

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Case Reports

Case 1. A 42-year-old caucasian woman was first noted to be hypertensive four years prior to admission. In January, 1973, renal arteriography showed severe fibromuscular dysplasia of both renal arteries (Fig. 1). The primary branches of the left kidney showed severe disease with aneurysmal dilatation and *ex vivo* reconstruction of this kidney appeared to be indicated. The stenosis in the right kidney involved a segment of the renal artery distal to the first bifurcation but, as no branch arteries were involved, *in situ* reconstruction appeared feasible. In February, 1973, a left *ex vivo* reconstruction was performed using the hypogastric artery and a right *in situ* repair using an interposition of autologous saphenous vein (Fig. 2). The patient refused a postoperative arteriogram and was normotensive until 9 months after surgery at which time she became hypertensive again. Arteriography showed a normal appearing left renal artery but showed stenosis of the interposed saphenous vein segment (Fig. 3). In September, 1973, the right kidney was removed and an *ex vivo* repair was performed, again using the hypogastric artery. The patient is normotensive 6 months after surgery.

Comment. This case emphasizes the failure of an autologous saphenous vein graft for *in situ* branch renal artery replacement and the feasibility of a successful *ex vivo* repair following a failed reconstruction.

Case 2. A 46-year-old woman with congenital absence of the right kidney underwent left ureterolithotomy 8 years previously. Two months prior to admission, the patient had flank pain and hematuria. Arteriography showed a large aneurysm arising from one of the segmental branches of the left renal artery (Fig. 3). Renal function was normal. In August, 1974, the patient underwent *ex vivo* repair of her left kidney. At the time, the saccular aneurysm was totally excised and the renal artery branches were reconstructed with an arterial autograft applied as a patch. Because of previous ureteral surgery, the ureter was not detached. Following repair, the kidney was placed in its normal position and reanastomosis of the main renal artery and renal vein was ac-

TABLE 1.

Patient Age	Duration of Hypertension	Left Kidney					Right Kidney					Date of Operation	Latest B.P.
		Disease	Repair	No. of Branches	Ureter	Graft	Disease	Repair	No. of Branches	Ureter	Graft		
N.P., 39	2 yrs	FM	EV	3	UV	hypo-gastric	FM	EV	2	UV	hypo-gastric	2/72	130/90
P.G., 43	5 yrs	FM	EV	3	UV	splenic	FM	Nephrectomy tomy	3			3/73	130/80
H.W., 42	4 yrs	FM	EV	2	UV	hypo-gastric	FM	IS	1	intact	saph vein	3/74	
							FM	EV	3	intact	hypo-gastric	11/74	114/86
D.F., 22	1 yr	FM	EV	2	UV	hypo-gastric			Normal			7/74	120/70
F.G., 14	1½ yrs	FM	EV	3	UV	hypo-gastric			Normal			8/74	120/80
E.E., 46	—	Aneurysm	EV	4	intact	hypo-gastric			Absent			9/74	130/90
C.H., 54	5 yrs	FM	IS	1	intact	external iliac	FM	EV	2	intact	common iliac & bifur-cation	10/74	140/80
P.F., 26	1 yr			Normal			FM	EV	4	intact	hypo-gastric	12/74	110/70
P.B., 22	2 yrs			Normal			FM	EV	3	UV	hypo-gastric	1/75	118/70
M.O., 39	2 yrs			Normal			FM	EV	3	intact	hypo-gastric	1/75	130/80

Note: F M—Fibromuscular dysplasia; EV—*Ex-vivo* repair; IS—*In situ* repair; UV—Uretero-vesicle implantation

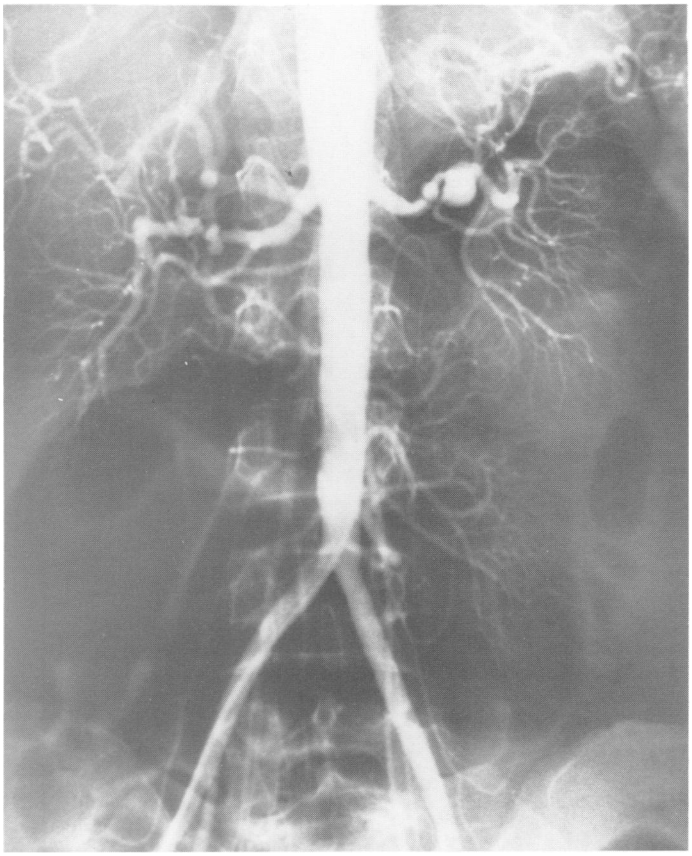

FIG. 1. Preoperative arteriogram of patient H. W. showing localized stenosis of the right renal artery distal to its first bifurcation and extensive left renal artery fibromuscular dysplasia.

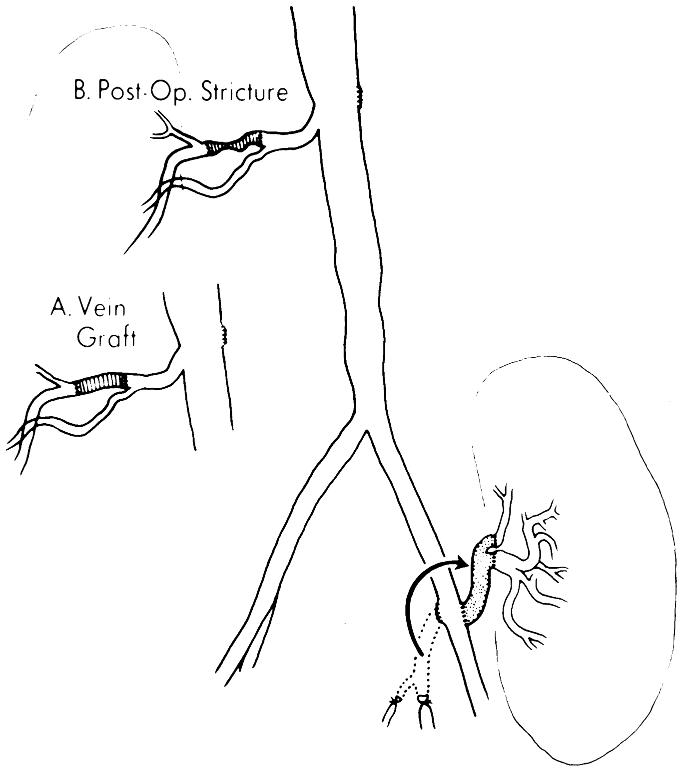

FIG. 2. Schematic drawing of the first arterial repair, patient H.W.

complished. Postoperative arteriography showed a patent arterial repair without evidence of the aneurysm. The patient has been asymptomatic since operation (Fig. 4).

Comment. This case demonstrates a successful *ex vivo* repair for a branch renal artery aneurysm without detachment of the ureter.

Case 3. A 54-year-old woman had been hypertensive for the past 5 years. Arteriography at the time of admission showed bilateral fibromuscular dysplasia. The disease in the right renal artery involved multiple branches. On the left only the main renal artery was involved (Fig. 5). In November, 1974, the patient underwent a right *ex vivo* repair and a left *in situ* repair. The arterial autograft was obtained by resecting the left common iliac artery, the internal iliac (hypogastric) artery and the external iliac artery. Continuity of the iliac vessels was restored with an 8 mm knitted graft. The common iliac artery with its bifurcation of internal iliac (hypogastric) and external iliac arteries was used for the *ex vivo* repair on the right. The remainder of the external iliac artery was used as an aorto-renal autograft to replace the diseased left main renal artery (Fig. 6). The patient has remained normotensive since surgery.

Comment. This case demonstrates the use of two surgical teams to reconstruct bilateral disease—right, *ex vivo* and left, *in situ*.

Case 4. A 14-year-old high school student was found on routine physical examination to be hypertensive. Complete workup including renal arteriography revealed a normal right kidney but the left kidney was supplied by two arteries. The larger inferior renal artery supplying most of the left kidney appeared to be normal. There was a collateral circulation in the mid portion of the superior renal artery where a focal defect was seen. The distal portion of the renal artery was opacified via the collateral (Fig. 7). In July, 1974, the patient underwent left *ex vivo* repair. The entire diseased upper renal artery was excised and reconstruction was performed using the patient's hypogastric artery (Fig. 8).

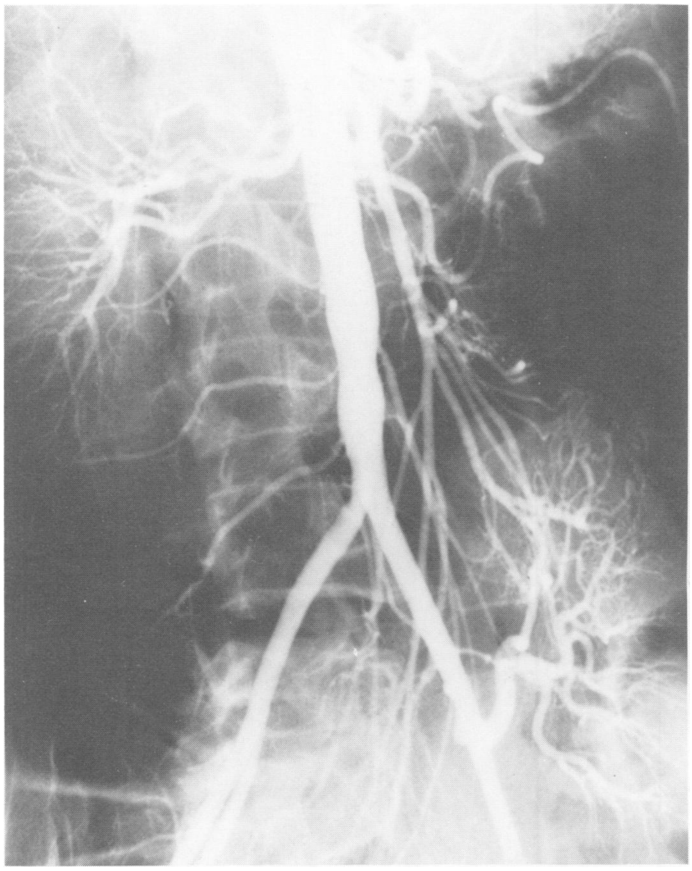

FIG. 3. Arteriogram of patient H.W. prior to second repair showing stenosis of interposed saphenous vein graft of the right kidney. The left autotransplanted kidney now has a normal arterial supply.

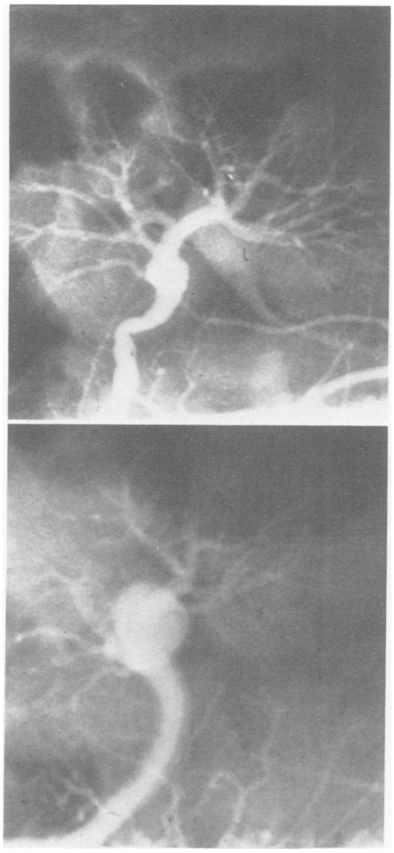

FIG. 4. Pre and postoperative arteriogram on patient E. E. showing the renal artery aneurysm and postoperative repair.

Subsequent examination of the upper polar artery revealed a septum completely obstructing flow to the upper pole of the left kidney. This area was supplied by collateral circulation only. The patient has remained normotensive since surgery.

Comment. This case demonstrates a successful *ex vivo* reconstruction in a child where renal preservation is critical.

Case 5. A 22-year-old woman was found to be hypertensive one year prior to admission. Her symptoms progressed in the 5 months prior to admission. Renal arteriography showed atrophy of the right kidney secondary to severe fibromuscular dysplasia. Total renal function was normal. Although the right kidney was atrophied, nephrectomy was not advised because of her age and the possibility of subsequent disease of her left kidney. A right *ex vivo* repair was performed using the hypogastric artery (Fig. 9). She has remained normotensive since her operation in January, 1975.

Comment. This case demonstrates that renal atrophy unless severe is no contraindication to *ex vivo* surgical repair.

Discussion

Renal autotransplantation was first described by Hardy in 1963[9] and was first successfully performed for renovascular hypertension by Woodruff in 1964.[18] Oda first reported nephrectomy with *ex vivo* microvascular reconstruction and successful autoimplantation in 1967.[15] In 1970, we described a technique of reconstruction of renal artery branches in laboratory animals using continuous extracorporeal hypothermic perfusion.[1] Cormal et al. were the first to report the clinical use of this technique.[5] In the last 5 years, many case reports or nephrectomy and *ex vivo* repair using either hypothermic perfusion of hypothermia alone have been published.[3,7,8,11,12]

Ex vivo surgery should be considered only when *in situ* surgical repair is deemed impossible. Extension of the disease to the primary renal artery branches does not necessarily preclude *in situ* repair. If the branches are 3 mm or more in diameter, *in situ* bifurcation reconstruc-

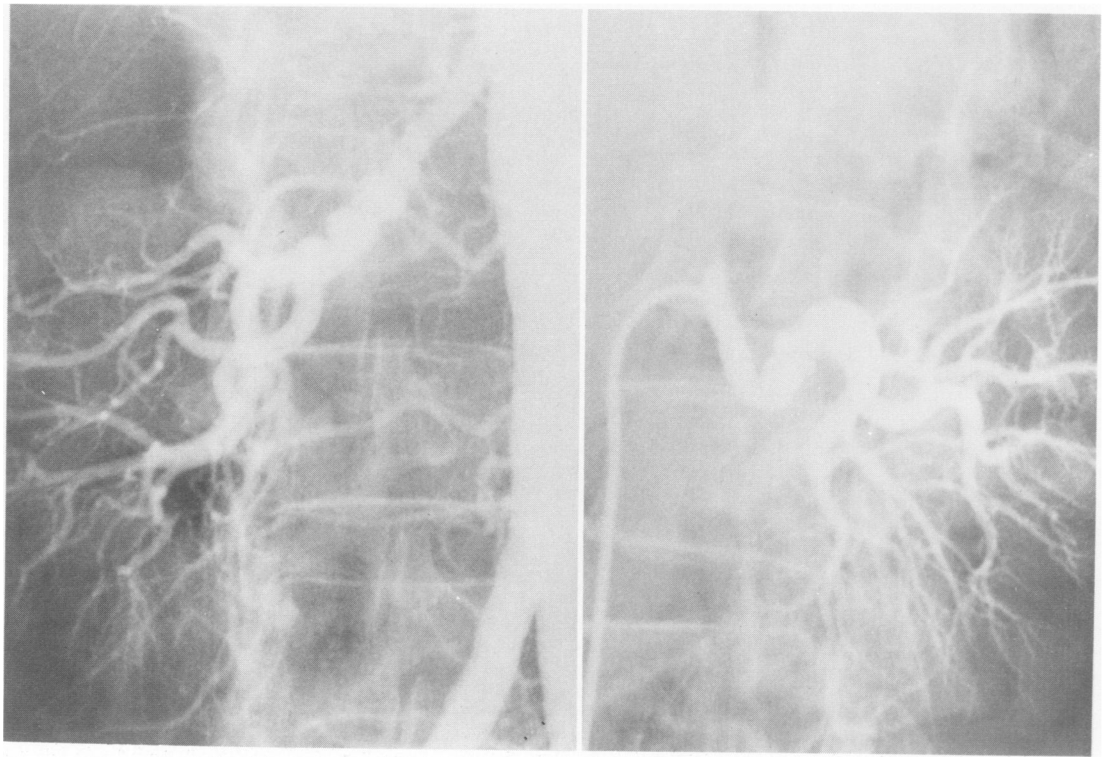

FIG. 5. Preoperative arteriograms on patient C. H. Note the short segment of patent renal artery proximal to the first bifurcation in the left kidney.

FIG. 6. Preoperative left and postoperative right arteriograms on patient C. H. showing patent *ex vivo* repair of the right kidney and patent *in situ* repair of the left kidney.

tion can be performed with relative ease. As suggested by Fry and others, minimal stenosis of branch arteries, especially if not associated with aneurysm, can be successfully dilated.[6]

In this report, arterial autografts were used for arterial reconstruction, rather than autologous saphenous vein grafts. In two recent publications the longterm fate of autologous saphenous veins used in aorto-renal bypass procedures was reported.[4,17] An alarming 40 to 60% incidence of graft abnormality, including thrombosis, dilatation, aneurysm formation or stenosis was found. However, the hypogastric artery has been used in thousands of renal transplant procedures with only suture line stenosis being observed. Furthermore, a recent survey of aorto-renal arterial autografts performed for renovascular hypertension at the University of California Medical Center in San Francisco showed none of these complications during a 10-year follow up period.[13]

Ex vivo repair can be performed by both continuous

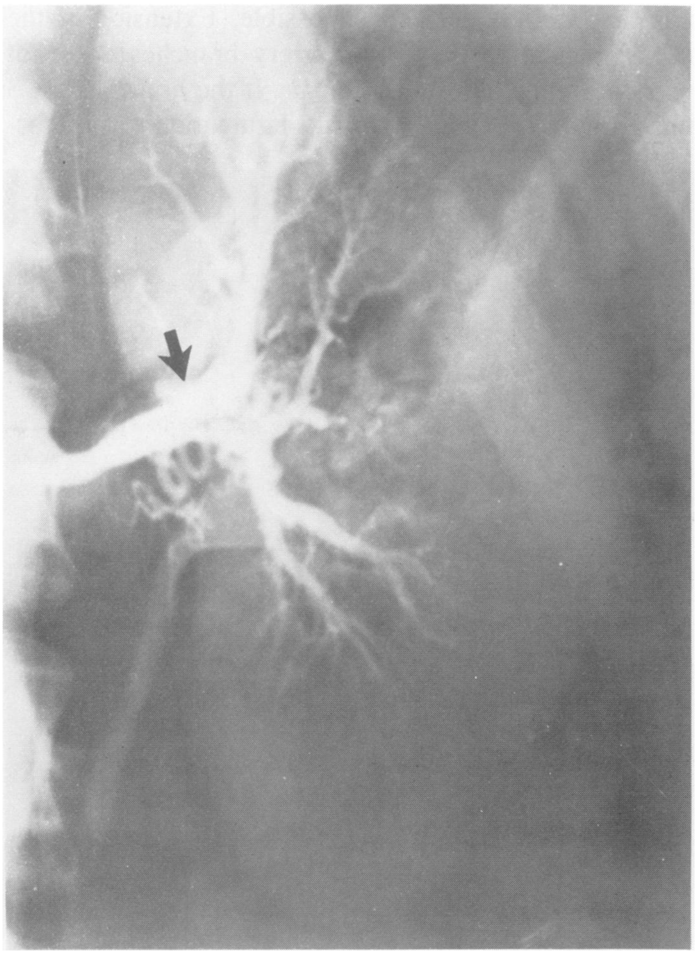

FIG. 7. Schematic drawing of dissecting platform and perfusion circuit.

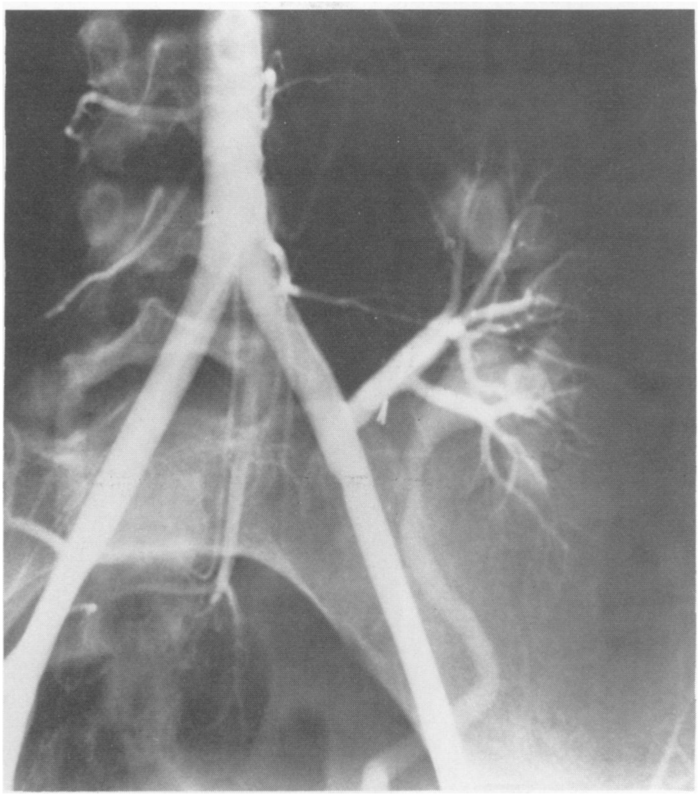

FIG. 8. Postoperative arteriogram on patient S. G. The normal lower polar artery was anastomosed end-to-side to the interposed hypogastric artery.

FIG. 9. Preoperative arteriogram on patient P. B. showing moderate atrophy of the right kidney and severe fibromuscular dysplasia of the right renal artery. The postoperative *ex vivo* repair is shown on the right.

hypothermic perfusion and simple cold storage. Three of the kidneys in this series were reconstructed using hypothermia alone and 8 were reconstructed during continuous hypothermic perfusion. The advantages of continuous perfusion are: (1) Dissection of the renal branches is easier as these vessels are distended. (2) Continued perfusion allows extra protection for the kidney even when the procedure is lengthy. (3) Following reconstruction, perfusion pressure can be set at systolic levels and small anastomotic leaks can be closed prior to autotransplantation. Bleeding after autotransplantation from unrecognized anastomotic leaks requires additional sutures *in situ*. This may be hazardous, especially if the bleeding site is a small vessel anastomosis in the renal hilum. When hypothermia alone is used, cold Ringer's lactate is an effective solution. There is no evidence that for the short period of time required for repair, hyperosmolar solutions provide greater protection than hypothermia with cold Ringer's lactate solution.[10]

Management of the ureter appears to be relatively unimportant. The ureter can be left intact during the reconstruction as long as retrograde bleeding into the kidney and/or perfusion is prevented by temporary occlusion of the ureter with a soft elastic tubing. Redundancy of the

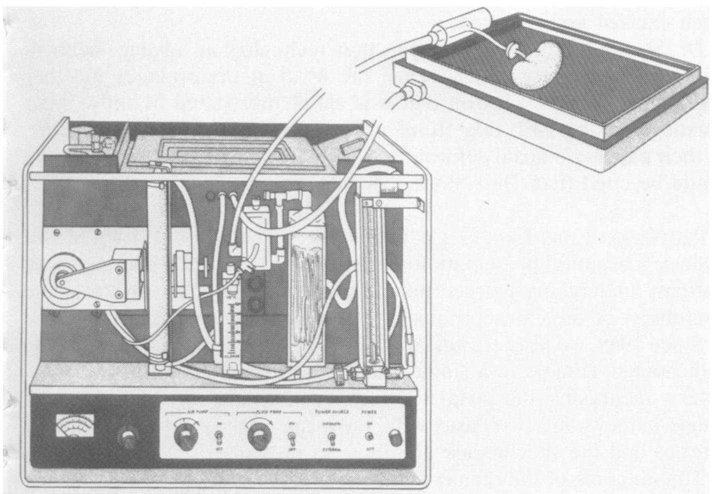

FIG. 10.

ureter appears to be no problem if the ureter is left intact and the kidney is reimplanted lower in the abdomen. However, if the surgeon is completely familiar with the techniques of renal transplantation, ureterovesicle implantation should have a complication rate of less than 0.5 per cent.[16] When one kidney only is being reconstructed, it is simple to leave the ureter intact and perform the reconstruction on a specially constructed platform placed on the patient's lower abdomen (Fig. 10). For bilateral reconstruction, detachment of the ureter allows complete removal of one kidney from the abdomen and permits a second team to work on the contralateral kidney *in situ* while the first kidney is reconstructed at an adjacent dissecting platform. As bilateral reconstructions can be lengthy, the use of two surgical teams can shorten the operative period.

Arteriography following *ex vivo* repair has been advised by some authors prior to replantation of the kidney.[5] Although our dissecting platform permits *ex vivo* arteriography, we have not used this technique because of the possible side effects and toxicities of the contrast medium. Usually the status of the disease has been accurately identified by preoperative selective arteriography. Following reconstruction, simple calibration with the commercially available dilators used for Scribner shunts, are useful to assess patency of anastomosis. If a contrast medium is used during or following the *ex vivo* repair it should not be recirculated and should be washed out of the kidney.

The decision whether a kidney should be repaired *in situ* or *ex vivo* should be made prior to surgery. Acting according to the concept that *in situ* repair should be attempted first and if it proves to be impossible then the kidney should be repaired *ex vivo* will probably give poor results. *Ex vivo* repair requires complete mobilization of the kidney. This requires additional time and is usually not done for *in situ* repair. Furthermore, the warm ischemia which occurs during an unsuccessful *in situ* repair may make the organ unsuitable for subsequent *ex vivo* repair.

The kidney should be removed under optimum conditions. This includes the use of mannitol and careful dissection so that vasospasm does not occur during the nephrectomy with tubular necrosis as a sequellae later.[14] Tubular necrosis causes reduced renal blood flow after reimplantation and thus increased the likelihood of thrombosis, especially if the repair involves multiple small vessels. The anastomosis should be done with fine sutures (6-0 or 7-0 Tycron is used). In young women we have reimplanted the kidney high on the iliac vein and iliac artery. This avoids a pelvic location of the kidney, whould there be subsequent pregnancies.

The indications for *ex vivo* reconstruction should be tailored to the individual patient's needs but in general are the following: 1) Failure of medical means to control hypertension, progression of the arterial lesions or decrease in renal function. 2) Lesions which are uncorrectable by *in situ* vascular reconstructive procedures. 3) Bilateral disease or unilateral disease in a single kidney, thus precluding nephrectomy. 4) Unilateral disease with a normal contralateral kidney in patients under 40 years of age. 5) Previously unsuccessful *in situ* repair (If the first reconstruction has failed due to a technical error, a second *in situ* reconstruction may be possible.) Extensive scarring from the previous procedure might make a second *in situ* procedure extremely difficult and *ex vivo* repair may be a safer alternative. Nephrectomy rather than *ex vivo* reconstruction is indicated for: 1) Unilateral disease in an elderly patient where the chance of recurrence of fibromuscular dysplasia in the normal kidney is unlikely or 2) Severe atrophy of the affected kidney which would be unimportant to preserve.

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Discussion

Dr. Thomas E. Starzl (Denver, Colorado): It has been obvious almost from the moment of its introduction that the preservation techniques of Belzer would revolutionize the practice of renal transplantation. It is also clear that non-transplant urologic practices and vascular surgical approaches may be affected as well, as Dr. Stoney has shown us so beautifully today. Drs. Stoney and Belzer have concentrated on the difficult renal vascular reconstructions which have also provided us with our main published experience now comprising 14 cases involving 18 kidneys.

(Slide) There are other indications than vascular lesions for the so-called bench work surgery, as Russ Scott has called it, including otherwise inoperable stone disease. This man had a staghorn calculus in his only kidney. The kidney was removed, bivalved while on the Belzer machine, cleaned out, and autotransplanted to the location seen here.

(Slide) This woman had a large carcinoma involving the lower two-thirds of her only kidney. She was treated in the same general way with protection of the kidney on the Belzer machine and reconstruction and autotransplantation of this rather small remnant. She has no evidence of recurrence now after more than a year.

We have also used autotransplantation to allow short ureters to be reimplanted into the bladder as was first described by James Hardy in 1963, and to protect kidneys on the Belzer machine while diffuse aneurysms of the abdominal aorta involving the renal blood supply have been excised and replaced.

Dr. Stoney's work has shown us how technological advancements in one area of surgery can advance the level of performance in other disciplines. This is a lesson that was eloquently stated by those great plastic surgeons, Milt Edgerton and Joe Murray, on Wednesday night, in their papers on facial deformities. No better example of this principle could be cited than Drs. Stoney and Belzer's brilliant work.

Professor Lars-Erik Gelin (Göteborg, Sweden): In relation to Dr. Stoney's beautiful presentation, I should like to report on our series of patients undergoing extracorporeal kidney surgery and illustrate the usefulness of the extracorporeal method with one special case.

Since 1968, we have treated 36 kidneys in 33 patients on the following indications: Tumors in a single kidney, bilateral kidney tumors, renal artery aneurysms and distal renal artery stenosis, coralloid stones in single kidneys and two cases with aortic aneurysm involving the renal arteries and the special case I'll come to presently.

The outcome of the repairs for distal renal artery stenosis producing severe hypertension appears on this slide. All patients except one became normotensive after the construction.